The status of breeding seabirds and herons at Ashmore Reef, off the Kimberley coast, Australia

Rohan H Clarke[1, 2], Michael Carter[3], George Swann[4] & Jim Thomson[1]

[1] School of Biological Sciences, Monash University, Clayton, Victoria 3800, Australia.

[2] ✉ Rohan.Clarke@monash.edu ph 0408 947 001

[3] 30 Canadian Bay Road, Mount Eliza, Victoria 3930

[4] PO Box 220, Broome, Western Australia 6725

Manuscript received December 2010; accepted January 2011

Abstract

Ashmore Reef is situated on the edge of Sahul Shelf, off the Kimberley coast, Australia. Surveys in 2010 indicate the three small islands within Ashmore Reef support approximately 100,000 breeding seabirds of 16 species and four heron species on an annual basis. That such a diversity and abundance of tropical seabirds utilize a total land area of just 55 ha for breeding purposes is exceptional in an international context. In this paper we review population sizes of breeding seabirds and herons at Ashmore Reef. Bayesian change-point models applied to count data spanning a 60 year period demonstrate that populations of breeding seabirds have increased at this location. Large ground-nesting seabirds display positive step changes in population size since the late 1980s whilst populations of shrub-nesting congeners display similar step changes since the late 1990s. We discuss the potential reasons for these abrupt population increases.

Keywords: seabirds, herons, Ashmore Reef, Kimberley, population size

Introduction

Ashmore Reef lies within Australian waters at 12°20'S, 123°0'E, some 630 km north of Broome and 325 km off the Kimberley coast (Fig. 1). The Ashmore Reef National Nature Reserve serves to protect marine ecosystems with high biological diversity (Commonwealth of Australia 2002). Ashmore Reef contains four vegetated islands (West, Middle and East islands and a recently vegetated cay; total land area ~55 ha), and several additional sandbanks that rise above the high water mark (Fig. 2) (Russell *et al.* 1993).

The available terrestrial habitats at Ashmore Reef support a large population of seabirds, including some of the most important seabird rookeries on the Sahul Shelf (Serventy 1952, Milton 2005, Bellio *et al.* 2007). The diversity of seabirds across the three main islands is exceptional in an Australasian context. It has been speculated that this diversity may have arisen because of the isolated nature of this island group, opportunities for both ground and shrub-nesting species on the islands and the proximity of Ashmore Reef to the Indonesian Through Flow – a potentially nutrient rich current linking the Pacific and the Indian Oceans that is active in the vicinity (Commonwealth of Australia 2002; Milton 2005; Potemra 2005; Bellio *et al.* 2007).

Many seabirds at Ashmore Reef are breeding visitors and are thus present in large numbers on a seasonal basis. Large colonies of Sooty Tern *Onychoprion fuscata*, Crested Tern *Thalasseus bergii*, Common Noddy *Anous stolidus*, Lesser Frigatebird *Fregata ariel* and Brown Booby *Sula leucogaster* breed on East and Middle islands. Smaller breeding colonies of Wedge-tailed Shearwater *Ardenna pacifica*, Masked Booby *Sula dactylatra*, Red-footed Booby *S. sula*, Great Frigatebird *Fregata minor*, Little Egret *Egretta garzetta*, Eastern Reef Egret *E. sacra* and Black Noddy *Anous minutus* also occur (Australian National Parks and Wildlife Service 1989; Milton 2005). Many of the bird species present in the region are listed under international treaties for migratory birds (JAMBA, CAMBA and ROKAMBA) and breeding seabirds are listed marine species under the *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth of Australia 2009). Ashmore Reef is recognised as a Ramsar wetland of international significance, with an area of 58,300 ha being designated in 2002 (Ramsar Convention Bureau 2009). Recently, Ashmore Reef has also been designated an Important Bird Area by BirdLife International on the grounds that it supports exceptionally large numbers of migratory and congregatory species (Birds Australia unpubl. data).

History of visitation and exploitation of the avifauna

The history and development of Ashmore Reef has been thoroughly reviewed by Russell (2005). The reef area and associated islands have an extended record of human visitation dating back ~300 years when Ashmore Reef was discovered by Indonesian fishers who originated from Roti Island (Fox 1977; Dwyer 2000). Initially, exploitation of marine resources by Indonesian fishers focussed on aquatic fauna such as fish and molluscs; seabirds were not harvested as they were considered special in aiding sailors to find land (Dwyer 2000). Subsequently, perhaps as more commercially orientated Indonesian fishers such as the Bajau began visiting the islands (Dwyer 2000), breeding seabirds and their eggs were also taken when available (see Serventy

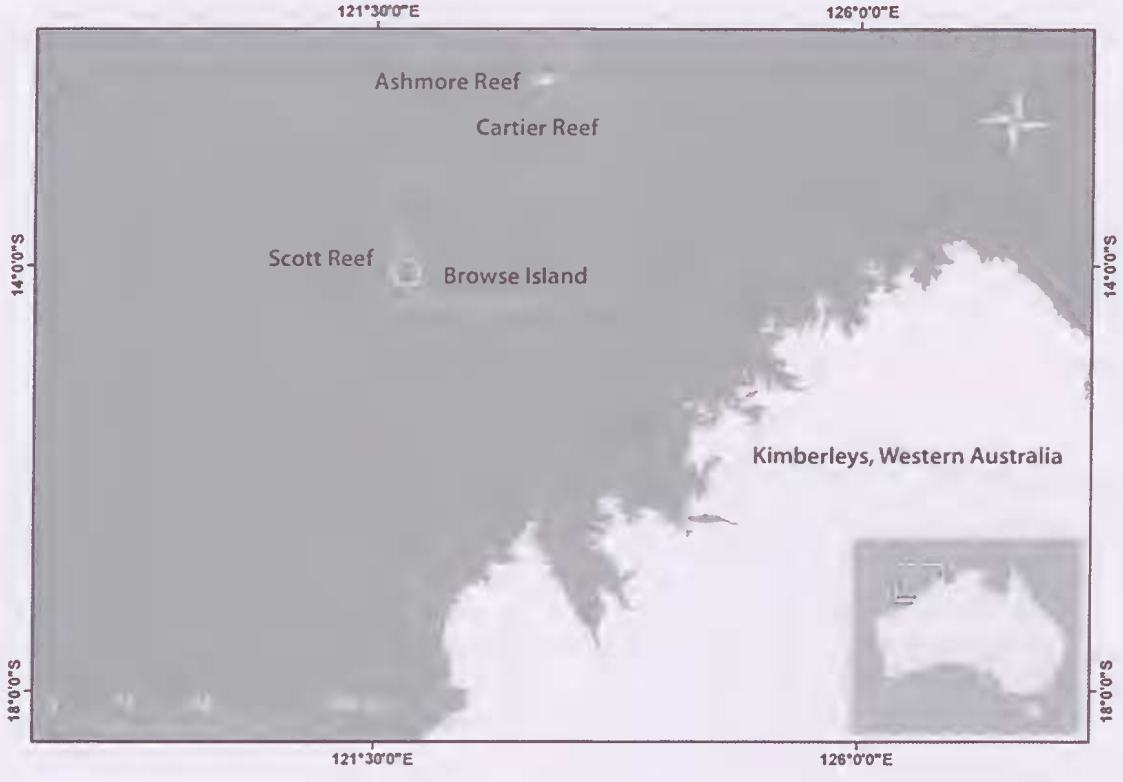

Figure 1. Location of Ashmore Reef, relative to the Kimberley coastline and other Australian reefs and islands in the region. The boxed outline surrounding Ashmore, Cartier and Scott reefs and Browse Island delineates the boundaries of the MOU 74 Box.

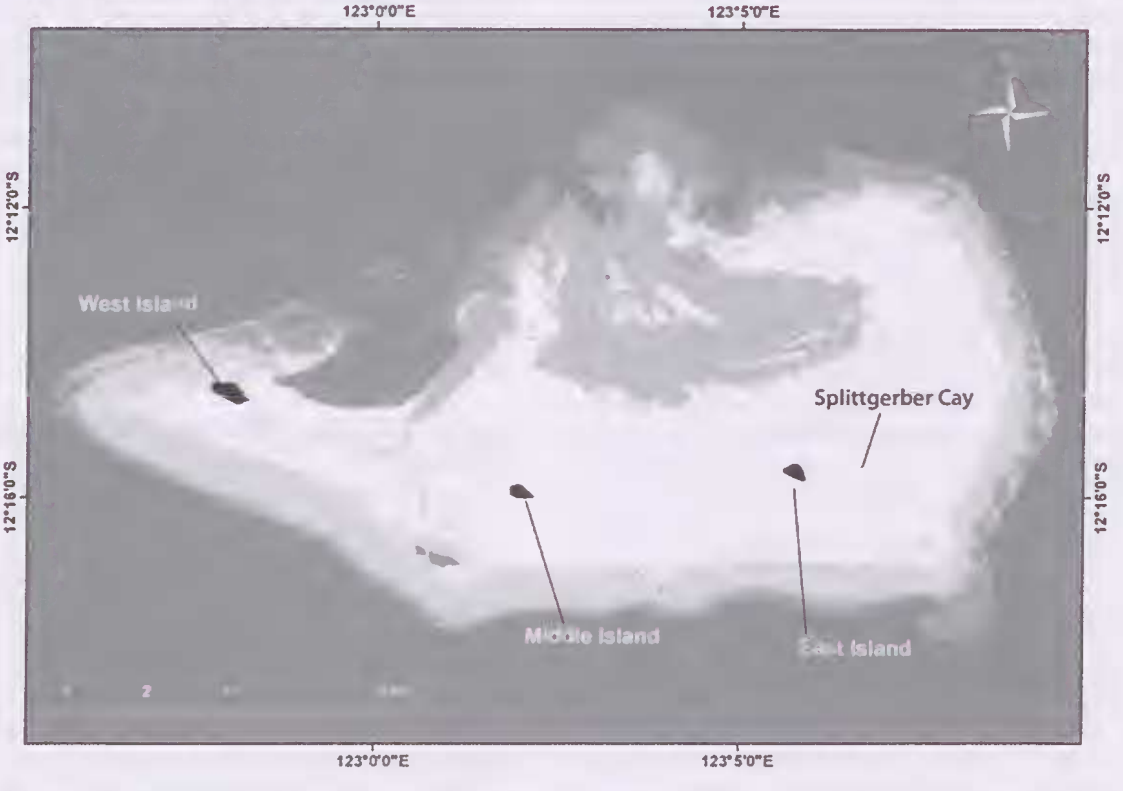

Figure 2. Overview of Ashmore Reef showing the locations and relative sizes of West, Middle and East islands and Splittgerber Cay. Palest shade of grey indicates depths < 4 m, darkest shade of grey indicates depths > 12 m.

1952; Clark 2000; Russell 2005). Ashmore Reef came to the attention of Europeans when Captain Samuel Ashmore chanced upon the area in 1811. Subsequent to this discovery the terrestrial habitats at Ashmore Reef were heavily exploited for guano such that by 1891 all significant phosphate reserves on the islands were exhausted (Woodward 1917; Fairbridge 1948; Langdon 1966; Russell 2005). In addition to disturbance to breeding seabirds by the activity of guano extraction, the presence of phosphate mining camps is also likely to have impacted on breeding seabirds, if for no other reason than adults and nest contents provided a ready source of protein.

During a visit by a CSIRO fisheries vessel in October 1949, Serventy (1952) gathered the first quantifiable data relating to the birds at Ashmore Reef. The expedition also reported some 30 Indonesian *perahus* (traditional fishing vessels) with a complement of ~300 men within the reef area. On that same visit the remains of birds killed by visiting Indonesian fishers were observed on all three islands. The 'take' was implied to be high with 'a small heap of remains of immature boobies' on West Island, a 'few remains of killed birds' on Middle Island and 'quantities of remains of birds killed by visiting fishermen' on East Island (Serventy 1952). Subsequent visits by naval vessels also reported numbers of *perahus* at the reef (Russell 2005) and in July 1974 the HMAS Diamantina reported Indonesian fishers cooking and drying seabirds on the islands (Australian National Parks and Wildlife Service 1989).

In 1974, a Memorandum of Understanding was signed by the Australian and Indonesian governments. Known as the 'MOU 74 Box', the area under the agreement incorporates Ashmore Reef and extends as far south as Browse Island and Scott Reefs (Fig. 1) (Australian National Parks and Wildlife Service 1989). Within the MOU 74 Box certain traditional fishing practices by Indonesian fishers were allowed to continue, but others, such as the harvesting of seabirds and marine turtles, were no longer permitted. Despite this agreement there remained heavy exploitation of resources at Ashmore Reef, including evidence of ongoing (now illegal) take of seabirds. For example, McKean (1980) reported the wings and skins of many Lesser Frigatebirds and Brown Boobies found at several Indonesian camps on West Island in November 1979. In an effort to control this, the then Australian National Parks and Wildlife Service established the Ashmore Reef National Nature Reserve in 1983. Soon after, in 1985, the then Department of Territories commenced a seasonal surveillance program at the reef to prevent the taking of seabirds and turtles. The program involved the presence of a contract surveillance officer during the traditional fishing season (March to November) of each year. This program, with improvements during 1987–88, met with considerable success (Russell 2005). Nevertheless, some illicit activities continued and in 1988 the Australian Government introduced new regulations banning all traditional fishing activities within the boundaries of the reserve (subsistence fishing in a narrow easement near West Island is still permitted). These regulations also prevent any landings by fishers or others on East and Middle islands (Commonwealth of Australia 2002). With the advent of suspected illegal immigrant vessels arriving at Ashmore Reef (the first vessel arrived in March 1995 (Clark 2000)), a year-round presence by Customs officers (who also act in a reserve warden capacity) aboard dedicated vessel(s) has further improved the protection of biodiversity assets within the reserve (R. Clarke pers. obs.).

Given the changing fortunes of seabirds at Ashmore Reef stemming from both enhanced legislative protection and a history of increasing on-ground enforcement, here we seek to provide a review of current population sizes of breeding seabirds within the reserve. Further, we seek to compare the current population estimates with historical data and discuss the implications of any observed population changes.

Methods

Collation, analysis and review of existing data

Counts of seabirds at Ashmore Reef date back to 1949 when Serventy visited the islands and documented the breeding species present (Serventy 1952). Thirty years passed before McKean (1980) visited in November 1979 and provided the next available summary of seabird numbers present within the reef. This visit marked the start of a period during which the avifauna of Ashmore Reef received considerable attention. In the following 19 years, counts of varying extent were documented on 68 occasions. These counts were principally undertaken by staff from the Australian National Parks and Wildlife Service (now the Federal Department of Sustainability, Environment, Water, Population and Communities (DSEWPC)) but observations by other visitors were also collated. These visits occurred in all calendar months, with at least two visits taking place in any year. A summary of these data has been presented by Milton (2005). Since 1996 (to October 2010) the authors have collectively visited Ashmore Reef on a further 15 occasions, with visits being made in all years since 2000, principally in October and November (10 visits) and January and February (three visits). Bellio *et al.* (2007) report on an additional visit (November 2004), when efforts were made to quantify seabird populations in relation to potential impacts by tropical fire ants *Solenopsis geminata*.

Counts of seabirds during the period 1979 to 1998 were of variable intensity and they were not all conducted by experienced observers (Milton 2005). Further, data held by the authors for this period (Commonwealth of Australia unpubl. data) does not quantify effort beyond specifying the island and the month and year of the visit (*i.e.* total time ashore and whether a count was complete or partial is not specified). In contrast, observations during visits by Milton (1999, 2005); Bellio *et al.* (2007) and the authors (Swann 2005a, 2005b, 2005c, this study) incorporate measures of effort. The methods employed by the authors to record birds have remained largely consistent between visits, with all species encountered being individually counted or, in the case of larger aggregations of seabirds, estimated. Importantly, all of these surveys have involved one or more experienced observers competent in the identification of seabirds in northern Australia and experienced in counting large aggregations of birds.

Potential limitations within the existing data are that visits were principally in October and November of each year (and to a lesser extent in January and February); that counts for some species were incomplete, dependent on the level of island access achieved; and that not all islands at Ashmore Reef were visited on every expedition.

In response to the Montara Well release (see discussion), a targeted field survey began in April 2010 to count seabirds present on the islands and sandbanks of Ashmore Reef in a rigorous and repeatable manner. Complete island-wide counts of seabirds were systematic with the observer recording the number of adults and the number of active nests for all species that were encountered. Active nests provide a more objective measure of seabird colony size (number of breeding pairs) than do counts of adults, as presence by one or both adults at a colony is dependent on breeding stage and time of day. Nevertheless, counts of adults provide the only option, when counts of nests are unachievable. For most species two separate counts were made – all active nests and all adults present (Great Frigatebird, Brown Booby, Red-footed Booby, Masked Booby, Crested Tern and Lesser Noddy *Anous tenuirostris*). In contrast, Sooty Tern, Bridled Tern *Onychoprion anaethetus*, Common Noddy and Black Noddy were nesting amongst herbaceous vegetation and in aggregations that precluded counts of individual nests. As many individuals of the above species, as well as Lesser Frigatebird, were yet to lay eggs and individual nests were not discernible a count of all adults[1] of each species was made. Each island was visited on at least three separate dates during the April 2010 surveys. For the three booby species, Great Frigatebirds and the less abundant tern species (*e.g.* Bridled Terns) single counts of nests and adults were made during each visit. For abundant species, or species that occur at very high local densities (*e.g.* Crested Terns) multiple counts by at least two observers were undertaken to ensure a degree of consistency in the final estimate of the maximum number present. Repeat counts were no longer considered necessary when ideal counts (*e.g.* birds not flushed by aircraft, no interruptions due to rain squalls) did not differ by more than 5%.

As some species of seabird are obligate ground-nesting species (*e.g.* Brown Booby, Masked Booby, Lesser Frigatebird), whilst others require elevated structures such as shrubs and trees (*e.g.* Red-footed Booby and Greater Frigatebird) we also provide an overview of recent vegetation changes at Ashmore Reef.

Statistical Analyses

Bayesian change-point models, using free-knot piecewise linear splines (Thomson *et al.* 2010), were applied to data for the large breeding seabirds that occupy Ashmore Reef to characterize temporal trends and objectively identify abrupt changes in these trends.

[1] As many seabirds are difficult to accurately age once they have left the nest adults are defined here as all free-flying individuals

The basic model for response variable y (*e.g.* counts of species x) at time t is expressed as:

$$y_t = \alpha_t + f(t) + \varepsilon_t \,, \qquad \text{equation (1)}$$

where, α_t is a time-dependent intercept, $f(t)$ is a continuous function of time, and ε_t is an error term with first order autocorrelation structure (see Thomson *et al.* 2010).

The time-dependent intercept allows for abrupt changes in y at some point in time, or step changes. Step changes are modelled as:

$$\alpha_t = \alpha_1 + \sum_{j=1}^{k_\alpha} \chi_j I(t \geq \delta_j) \,, \qquad \text{equation (2)}$$

where α_1 is the species count at time zero (earliest count), k_α is the number of step changes, δ_j is the timing of the j^{th} step change, and χ_j is the value of the change. $I(t \geq \delta_j)$ is an indicator function that equals 1 when $t \geq \delta_j$ and is 0 otherwise.

The temporal trend, $f_t(t)$, is modelled as a piecewise linear regression with an unknown number k_β of changes in slope, or trend changes, and a corresponding set of times θ_j of trend changes:

$$f_t(t) = \beta_1 t + \sum_{j=1}^{k_\beta} \beta_{[j+1]} (t - \theta_j)_+ \,, \qquad \text{equation (3)}$$

where the term $(t-\theta_j)_+$ equals $I(t \geq \theta_j)(t-\theta_j)$.

Given a particular intercept, the term is a piecewise linear and continuous function of time, but when the intercept α_t varies, the combination $\alpha_t + f_t(t)$ is a discontinuous piecewise linear model.

In this model there are four key parameters that determine the number, k_α and k_β, and timing, δ_j and θ_j, of change-points. Using a Bayesian framework with reversible jump Markov chain Monte Carlo sampling (MCMC, Lunn *et al.* 2006; 2009) we evaluated, via likelihood functions, the relative evidence in the data for all possible models, or combinations of change-points. The relative support for each model is expressed as a posterior model probability. The range of models considered possible is specified in the prior distributions for these parameters. Given no prior information or expectations, very vague priors can be used that essentially let the data determine the most likely values of each parameter, although hyper-parameters must still be set which determine the penalty for complexity (and therefore the degree of smoothness in the fitted trend). The resulting posterior distributions allow for probabilistic inferences about the occurrence of change-points in particular years, accounting for uncertainties in both data and other model parameters (including magnitudes and timing of other change-points).

Bayesian models were applied to the suite of large breeding seabirds (frigatebirds and boobies) that occur at Ashmore Reef as it is these species for which human depredation has been most frequently reported (*e.g.* Serventy 1952; McKean 1980; Australian National Parks and Wildlife Service 1989). As seabird numbers at Ashmore Reef vary considerably throughout the year

(this study), and existing count data is biased towards certain seasons, only count data collected in the period September to November of any year was incorporated in analyses. Data were excluded in situations where only one island had been counted within a calendar month. Remaining counts for each species were summed across all three islands. To account for situations where only two of the three islands were counted, a term was included in the model for the number of islands surveyed. This approach accounted for the inevitably lower counts when only two islands were surveyed (c.f. all three). Trends modelled are therefore the expected total count for each species across all islands at Ashmore Reef.

Results

Terrestrial environments

The vegetation at Ashmore Reef has been well documented by Pike & Leach (1997). As one would anticipate for isolated island environments, vegetation communities are simplified. On West Island there is a single dominant shrub species, *Argusia argentea*, two Coconut Palms, several other shrubs represented by very small numbers of individuals and a range of creepers, annual herbs and grasses (Pike & Leach 1997; April 2010, this study). In October 2010 there were two living *Argusia argentea* shrubs less than 80 cm in height on Middle Island and no apparent shrubs on East Island (this study). All other vegetation on these two islands is characterised by ground creepers, annual herbs and grasses. The current vegetation on East and Middle islands reflects considerable change since the publication of Pike & Leach (1997). All three Coconut Palms on Middle Island have died, with a single dead stem remaining near the now abandoned well. Similarly, shrubs reported by Pike & Leach (1997) that occurred on Middle and East Island have also since died. The dead remnants of *Scaevola taccada* shrubs now serve as the principal nesting sites for both Red-footed Boobies and Great Frigatebirds on Middle Island.

A sandbank to the east of East Island is now vegetated (first noted October 2009, this study). Three grass species were present on Splittgerber Cay in April 2010, when the total vegetated area was measured at 1150 m^2. Whilst there is some evidence that both Brown Booby and Eastern Reef Egret have started nesting on this cay this change is so recent (first evidence of nesting observed in October 2010) as to have no bearing on existing count data (R. Clarke unpubl. data).

The total land area of the three main islands at Ashmore Reef has been previously reported, yet there appears to be considerable variation in the literature as to the actual size of each (*e.g.* Carter 2003; Bellio *et al.* 2007; Clarke *et al.* 2009). As these islands may be somewhat dynamic, reported variation in part may reflect changes following disturbance and deposition events (*e.g.* cyclones), however it also seems likely that some of the observed variation is due to inaccurate or 'casual' estimates of total land area. During April 2010 the land area for each island was measured at the high tide line, using a GPS unit. West Island had a total land area of 28.1 ha, Middle Island had a total land area of 13.0 ha and East Island had a total land area of 13.4 ha.

Breeding seabirds

Sixteen species of seabird and four species of heron have been reported to breed at Ashmore Reef. The

Table 1

Recent (post-1990) breeding distribution of seabirds and herons on the three main islands of Ashmore Reef, Australia. 'Not observed' indicates *breeding activity* has not been reported, but adults of these species may still have been observed ashore at times. Question marks indicate some level of uncertainty.

Species	West Island	Middle Island	East Island
Wedge-tailed Shearwater	Regular	Not observed	Not observed
Red-tailed Tropicbird	Regular	Occasional?	Occasional?
White-tailed Tropicbird[1]	Regular	Occasional	Occasional?
Masked Booby	Not observed	Regular	Regular
Red-footed Booby	Not observed[2]	Regular	Regular
Brown Booby	Not observed	Regular	Regular
Great Frigatebird	Not observed[2]	Regular	Occasional?
Lesser Frigatebird	Not observed	Regular	Regular
Crested Tern	Occasional	Regular	Regular
Lesser Crested Tern	Not observed	Unconfirmed	Unconfirmed
Roseate Tern	Not observed	Occasional	Occasional
Bridled Tern	Not observed	Regular	Regular
Sooty Tern	Not observed	Regular	Regular
Common Noddy	Not observed	Regular	Regular
Black Noddy	Not observed	Regular	Regular
Lesser Noddy	Not observed	Regular?	Regular?
Eastern Great Egret	Not observed	Occasional?	Not observed
Little Egret	Occasional	Occasional?	Occasional?
Eastern Reef Egret	Regular	Regular	Regular
Nankeen Night-Heron	Occasional	Not observed	Not observed

[1] Latin names are presented in the text except for White-tailed Tropicbird *Phaethon lepturus* Lesser Crested Tern *Thalasseus bengalensis*, Roseate Tern *Sterna dougallii*, Nankeen Night Heron *Nycticorax caledonicus* and Eastern Great Egret *Ardea modesta*.

[2] Has roosted on West Island on occasion (*e.g.* Oct 2010) and may be prospecting.

highest diversities and greatest densities of breeding seabirds and herons are found on Middle Island (14–17 breeding species per year) and East Island (12–16 breeding species per year) with West Island hosting the largest colony of Eastern Reef Egret, the only colony of Wedge-tailed Shearwaters and most of the breeding tropicbirds (Table 1). The seabirds present at Ashmore Reef display a variety of reproductive strategies (Fig. 3). Most species breed annually, several species breed biannually and a small number of species have been reported to breed at Ashmore Reef sporadically (Table 1). Most seabirds at Ashmore Reef breed through the tropical dry season (May to November), with the majority of species commencing egg laying and incubation in April. These include Lesser Frigatebird, three species of noddy and Brown Booby. Red-footed and Masked Boobies also breed through the dry season, however specific months for egg laying are less well defined and documented. Several other species display a more variable response to season. For example, Crested and Sooty Terns have been reported to commence laying at various times including the months of January, April and November. In contrast Wedge-tailed Shearwaters appear to be the only obligate wet season breeder, though available data indicates both species of tropicbirds are also most abundant between the months of January and April. Eastern Reef Egrets, which are the only abundant heron species present within the reserve system, have been reported breeding in most months (Fig. 3).

Counts conducted in April 2010 occurred when the majority of dry season breeding species were present and many of these had commenced incubation. Thirteen of the 16 breeding seabirds at Ashmore Reef were attending active nests at this time, though no herons or egrets were observed breeding (Tables 2–4). As all seabirds on both East and Middle islands were counted over consecutive days and because most species were attending nests it is considered appropriate to pool these data to provide total measures of abundance. Approximately 72,000 breeding seabirds were utilizing islands on Ashmore Reef at the time of the April 2010 survey. Notable counts included 44,805 Common Noddies, 4379 Brown Boobies nests (extrapolated to 8758 breeding adults), 5382 Crested Terns and 4277 Lesser Frigatebirds (Tables 3–4). Whilst numbers are not as spectacular, the largest reported colony sizes at Ashmore Reef for Great Frigatebird (40 nests), Red-footed Booby (101 nests), Masked Booby (33 nests) and Red-tailed Tropicbird *Phaethon rubricauda* (17 nests) were also obtained during April 2010. Lesser Noddy was also confirmed as a breeding species at Ashmore Reef with 13 adults and four nests observed.

Change-point analyses

For the purposes of this review, change-point analyses focuses on the five large-bodied seabirds that breed at Ashmore Reef. For the three ground-nesting species (Brown Booby, Masked Booby and Lesser Frigatebird), change-point models identified positive step changes with significant posterior support in the period 1985 through until 2002 (Fig. 4). For the two shrub-nesting species (*i.e.* Red-footed Bobby and Great Frigatebird) similarly applied models identified positive step changes with significant posterior support during the period 1998 to 2003 (Fig. 4).

The ground-nesting Brown Booby is the most abundant of the *Sulidae* at Ashmore Reef, reflecting a remarkable recovery. In October 1949 Serventy (1952)

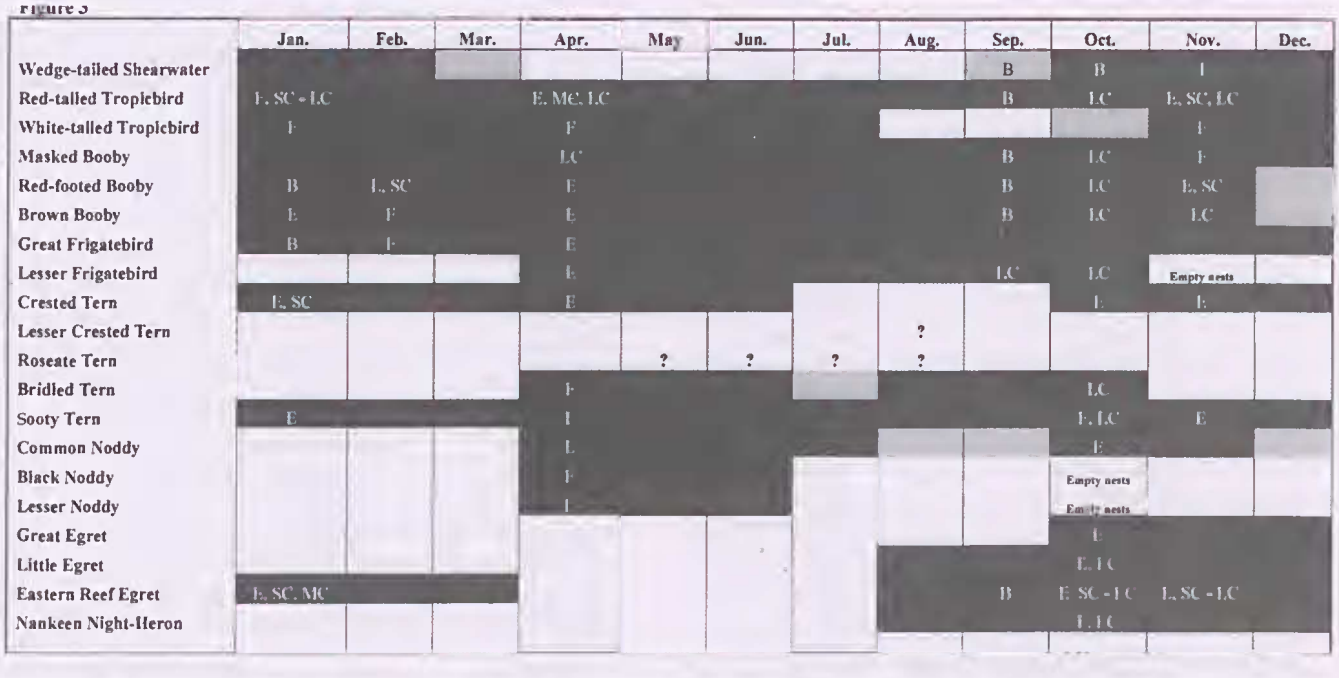

Figure 3. Breeding seasons of seabirds and herons at Ashmore Reef. Breeding months (seabirds) are shaded dark grey, pale grey indicates 'shoulder' months. Letters denote reported reproductive stage; E = eggs; SC = small chick; MC = medium chick; LC = large chick or fledgling; B = breeding reported but the reproductive stage not specified. Data sourced from Milton (2005), Swann (2005a, 2005b, 2005c), Bellio *et al.* (2007) and authors unpubl. data. Known breeding stages extrapolated to breeding seasons using data in Marchant & Higgins (1990a, 1990b), Higgins & Davis (1996). Unshaded cells indicate there is no *evidence* of breeding, though for many species breeding may still take place in these months.

Table 2

Counts of tropicbirds and Eastern Reef Egrets on West Island, Ashmore Reef. Counts were obtained during 17 visits between October 1998 and October 2010. In instances where several counts were made over consecutive days the highest count from that period is presented. Tropicbird records from Middle and East Islands are presented in Tables 3 and 4.

	Oct-1998	Oct-2000	Oct-2001	Nov-2001	Jan-2002	Feb-2003	Sep-2003	Oct-2004	Nov-2004	Jan-2005	Oct-2005	Oct-2006	Oct-2007	Oct-2008	Oct-2009	Apr-2010	Oct-2010
Red-tailed Tropicbird																	
adults	0	4	2	10	8	10	20	4	4	17	12	4	4	10	3	24	8
nests	0	2	1	5	2	4	7	2	3	14	3	3	3	8	1	17	2
White-tailed Tropicbird																	
adults	0	0	0	4	2	4	3	3	0	8	0	3	3	4	1	3	5
nests	0	0	0	2	1	0	0	2	0	2	0	0	0	0	0	1	1
Eastern Reef Egret																	
adults	Not reported	100	300	300	191	150	200	400	–	400	200	500	300	700	400	250	300
active nests?	–	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes

Sources: authors unpublished data, Swann (2005a), Swann (2005b), Swann (2005c), Milton (2005), this study

Table 3

Seabird counts at Middle Island, Ashmore Reef. The maximum count of adult seabirds obtained during 48 visits between 1979 and 1998 and counts of adult seabirds during 12 visits between January 2002 and October 2010 are shown. In instances where several counts were made over consecutive days the highest count from that period is presented. Numbers in bold indicate breeding of that species was explicitly reported for that count. All counts refer to adults except Brown Booby in April 2010 (n = active nests).

Date	Max. count 1979–1998	Jan 2002	Jan 2003	Sep 2003	Oct 2004	Jan 2005	Oct 2005	Oct 2006	Oct 2007	Oct 2008	Oct 2009	Apr 2010	Oct 2010
Red-tailed Tropicbird	1	0	1	1	1	0	0	2	0	0	0	0	0
White-tailed Tropicbird	6	0	3	0	0	2	0	1	1	1	0	0	1
Masked Booby	3	4	3	2	3	14	10	20	10	20	30	28	1
Red-footed Booby	15	46	42	40	60	220	30	50	80	80	100	101	12
Brown Booby	1050	1530	1250	1000	1000	2300	1000	2000	5000	1000	3000	2841n	940
Great Frigatebird	24	8	4	2	3	20	20	30	20	20	20	65	10
Lesser Frigatebird	1991	1000	300	100	300	300	200	2000	800	300	1000	2504	1160
Crested Tern	400	150	105	300	60	325	70	500	300	10	250	2814	125
Bridled Tern	239	0	0	0	10	0	0	5	8	1	2	50	15
Sooty Tern	40000	15000	5000	50	5000	50	3000	10000	15000	100	500	2500	280
Common Noddy	10000	1500	260	5000	15000	60	200	3000	700	2000	1800	13875	17000
Black Noddy	120	100	3	2	6	0	10	5	5	0	30	180	80
Lesser Noddy	120	0	0	0	0	0	0	0	0	0	1	7	3

Sources: authors unpublished data, Swann (2005a), Swann (2005b), Swann (2005c), Milton (2005), this study

Table 4

Seabird counts at East Island, Ashmore Reef. The maximum count of adult seabirds obtained during 51 visits between 1979 and 1998 and counts of adult seabirds during nine visits between January 2002 and October 2010 are shown. In instances where several counts were made over consecutive days the highest count from that period is presented. Numbers in bold indicate breeding of that species was explicitly reported for that count. All counts refer to adults except Brown Booby in April 2010 (n = active nests).

	Max. count 1979–1998	Jan 2002	Jan 2003	Jan 2005	Oct 2005	Oct 2006	Oct 2007	Oct 2009	Apr 2010	Oct 2010
Red-tailed Tropicbird	6	1	1	0	0	0	0	0	0	0
White-tailed Tropicbird	1	0	0	0	2	2	5	0	0	0
Masked Booby	9	5	25	4	10	5	15	8	10	6
Red-footed Booby	0	0	12	8	10	12	40	30	20	10
Brown Booby	500	1800	2000	2200	1000	3000	3000	1900	1538n	850
Great Frigatebird	2	0	4	0	5	2	10	0	0	1
Lesser Frigatebird	140	800	2000	600	300	1000	500	300	1773	470
Crested Tern	2700	310	310	150	10	10	400	85	2568	2
Bridled Tern	2400	0	0	0	3	5	6	5	300	10
Sooty Tern	20000	25000	10000	350	10000	10000	10000	7000	5000	8000
Common Noddy	54000	3000	1800	530	3000	5000	400	1070	30930	3000
Black Noddy	375	1500	5	3	20	10	20	70	450	1
Lesser Noddy	20	0	0	0	0	0	0	0	6	0

Sources: Swann (2005a), Swann (2005b), Swann (2005c), Milton (2005), this study

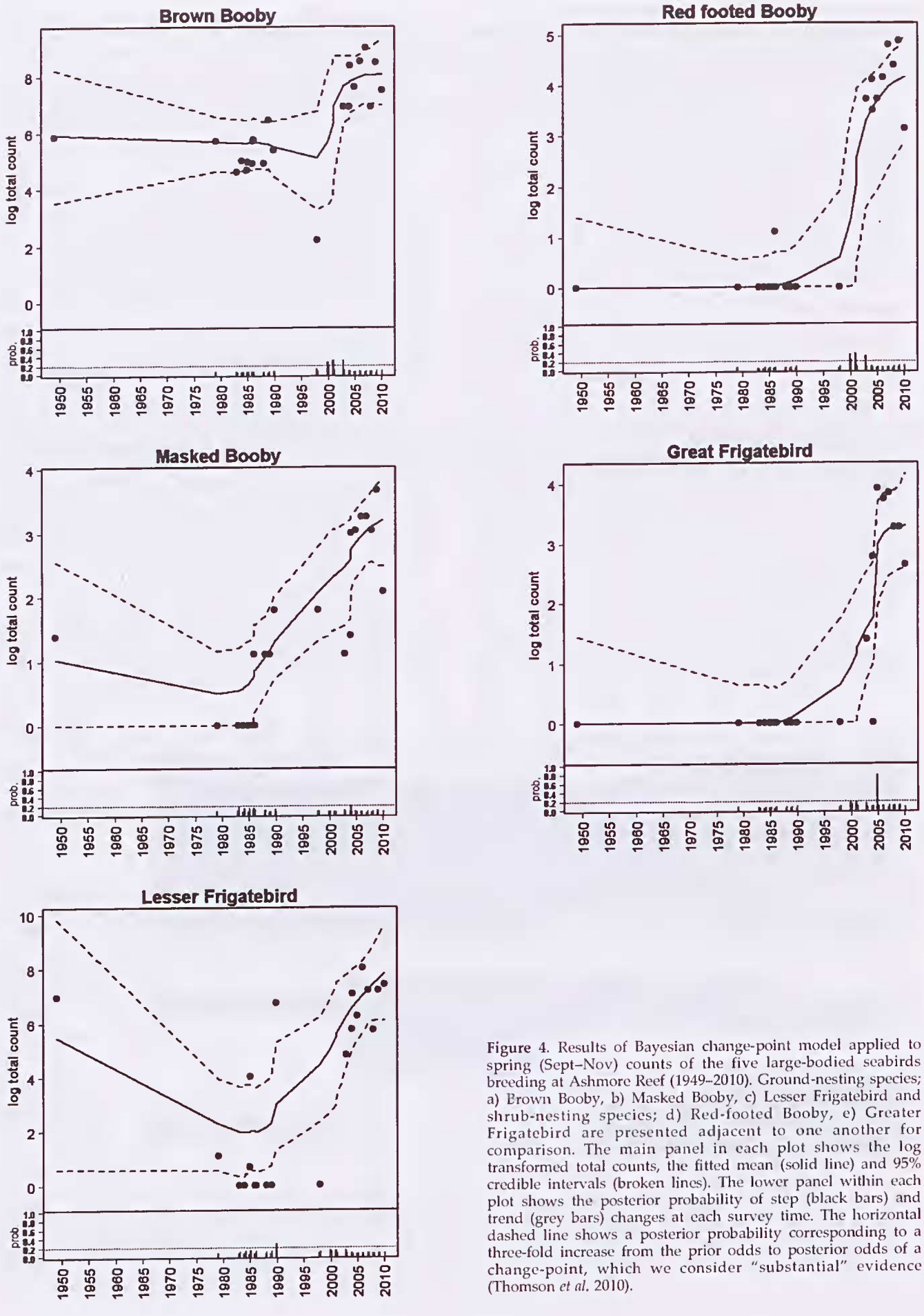

Figure 4. Results of Bayesian change-point model applied to spring (Sept–Nov) counts of the five large-bodied seabirds breeding at Ashmore Reef (1949–2010). Ground-nesting species; a) Brown Booby, b) Masked Booby, c) Lesser Frigatebird and shrub-nesting species; d) Red-footed Booby, e) Greater Frigatebird are presented adjacent to one another for comparison. The main panel in each plot shows the log transformed total counts, the fitted mean (solid line) and 95% credible intervals (broken lines). The lower panel within each plot shows the posterior probability of step (black bars) and trend (grey bars) changes at each survey time. The horizontal dashed line shows a posterior probability corresponding to a three-fold increase from the prior odds to posterior odds of a change-point, which we consider "substantial" evidence (Thomson *et al.* 2010).

reported approximately 40 birds over West Island but no nesting, 200 birds at Middle Island including many free-flying immature birds, and a few adults but no young on East Island. In 1979 McKean reported 300 on East Island but no birds on West or Middle Island (McKean 1980). Between 1983 and 1988 Milton (2005) estimated that between zero and 20 pairs nested there in any year. In the late 1990s, a high count of 1050 on Middle Island in May 1998 and 293 on East Island in the same month was documented (DSEWPC unpubl. data). This upward trend continued through the last decade such that by April 2010 4379 nests (extrapolated to 8758 breeding adults) were counted across Middle and East islands (Tables 3 and 4, Fig. 4).

Small but increasing numbers of the ground nesting Masked Booby breed on Middle and East islands. In October 1949 Serventy (1952) recorded a single adult on East Island and two adults on Middle Island. Between 1983 and 1988 Milton (2005) estimated up to two pairs nested there in any one year. More recent data demonstrates the population has been increasing, with 28 birds counted across Middle and East islands in January 2003 (Tables 3 and 4). The highest count to date was obtained in April 2010 when a total of 38 adults were ashore and 33 active nests were located. After an apparent period of absence (there are no records between 1979 and 1986 despite 44 survey visits to Middle Island and 36 survey visits to East Island during this period; DSEWPC unpubl. data), the species has now successfully recolonised Ashmore Reef (Fig. 4).

The Red-footed Booby is either a recent colonist at Ashmore Reef or it has re-established after a long period of absence. Serventy (1952) reported 'some substantial old nests in a clump of tall bushes' on West Island and suggested they may have belonged to the Red-footed Booby, though he was unable to confirm this and did not observe any individuals. Milton (2005) did not report any Red-footed Boobies nesting within the reserve up to 1988; the first reports of birds ashore were in May 1995 when two individuals were noted on Middle Island (DSEWPC unpubl. data). Since 2000, birds have been present during every documented visit to Middle Island. Subsequently, the species colonised East Island during 2002. The highest count of nests was obtained in April 2010 when a total of 101 active nests were recorded across Middle (91 nests) and East islands (10 nests) (Fig. 4).

Although Serventy (1952) reported that the Lesser Frigatebird was the predominant nesting bird on Middle Island, much of the evidence for breeding was in the form of 'heaps of young birds remains (heads, down and quills)' amongst 442 live young. While McKean (1980) also reported the 'wings and skins of many at several Indonesian camp sites', depredation was such that he detected no breeding activity and observed just two adults in flight during his entire visit. Milton (2005) reported between zero and 750 Lesser Frigatebird pairs bred at Ashmore Reef between 1983 and 1988. Since that time numbers have gradually increased (Fig. 4). By January 2003, 2300 birds were reported to be nesting across both breeding islands (Swann 2005b). More recently in April 2010, 4277 adults were counted across Middle and East islands (Tables 3 and 4, Fig. 4).

On the first occasion that the Great Frigatebird was ever recognised at Ashmore Reef, 24 birds were counted (Middle Island, May 1995; DSEWPC unpubl. data). Since that time numbers have generally remained stable with regular counts of ~20 in the last five years (Table 3) and a high count of 65 adults and 40 active nests in April 2010 (Tables 3 and 4, Fig. 4).

Discussion

The islands of Ashmore Reef support internationally significant numbers of seabirds (Milton 2005, Bellio *et al.* 2007). Up to 54,000 Common Noddies, 45,000 Sooty Terns, 5000 Brown Boobies and in excess of 4000 Lesser Frigatebirds have been reported to breed on Middle and East Island (Milton 2005, DSEWPC unpubl. data, this study; Tables 3 and 4). Some of these colonies are amongst the largest breeding colonies of that species in the Australasian region. For example Bellio *et al.* (2007) report that Ashmore Reef supports the largest colony of Sooty Terns in Western Australia and the second largest colony of Common Noddy in Australia. Although previous authors have concluded that Ashmore Reef may support up to 50,000 breeding seabirds (Milton 2005; Bellio *et al.* 2007), data presented here demonstrates the total number of breeding seabirds currently approximates 100,000 individuals[2] during a 12 month cycle. The significance of Ashmore Reef as a site for breeding seabirds is further highlighted by the fact that most seabirds are listed under one or more of the bilateral migratory bird agreements to which the Commonwealth of Australia is a signatory (JAMBA, CAMBA and ROKAMBA). As these bird agreements are incorporated in national environmental legislation all species are also listed under the *EPBC Act 1999* as marine species and/or migratory species (Commonwealth of Australia 2009).

A rigorous monitoring program that commenced in April 2010 is already producing valuable insights into seabird populations at Ashmore Reef. Not only have these counts demonstrated that seabird abundances at Ashmore Reef are larger than previously thought, clarification of the status of individual species is also occurring. For example, questions regarding the identity of Lesser Noddy at Ashmore Reef have previously been raised (Australian National Parks and Wildlife Service 1989; Stokes and Hinchey 1990; Higgins & Davies 1996; Commonwealth of Australia 2002). Observations and photographs of this species carrying nesting material, alighting on newly constructed nest platforms and of a single nest containing an egg confirm the species status as a breeding seabird within the reserve, albeit with a very small population (also Johnstone and Storr 1998).

Sixty years of counts

Despite the remoteness of Ashmore Reef, observations of seabird numbers date back to 1949, with more regular counts taking place since 1979. Although there were extended periods during which no data were collected,

[2] ~72,000 adult seabirds were counted in April 2010. As this number does not include any adults foraging at sea at the time of the counts, nor many individuals of breeding species that breed at a later date in the year (*e.g.* Wedge-tailed Shearwater, Roseate Tern) a total seabird population of 100,000 over a 12 month cycle is considered a conservative estimate.

this dataset has proved invaluable to assess the changing fortunes of seabirds at Ashmore Reef. Whilst many species were present and breeding in moderate numbers during 1949 it is apparent that a number of these species were driven to near local extinction due to excessive harvesting in subsequent decades. Although literature implicates traditional fishermen from Indonesia for much of this take (Serventy 1952; McKean 1980; Australian National Parks and Wildlife Service 1989; Russell 2005), there can be little doubt that guano collection prior to the existence of any count data will also have had its impacts.

Following the ratification of the Ashmore Reef Nature Reserve in 1983 the regions seabirds have received increasing protection. This commenced with enforcement patrols soon after the reserve was established (Russell 2005). Increasing levels of surveillance have culminated in a permanent presence by enforcement agencies at Ashmore Reef in recent years and this is reflected in the growth of breeding seabird populations at Ashmore Reef.

For the large breeding species of seabird (*i.e.* boobies and frigatebirds) increased protection following the more permanent presence of staff from border protection agencies and DSEWPC (and its predecessors) has led to marked changes in status. Indeed, positive responses that reflect a stepped change in abundance were detected for all five species subjected to Bayesian change-point modelling. Stepped changes in populations of large ground-nesting seabirds occurred up to a decade earlier than was observed for the two shrub-nesting species. Such a difference most probably reflects the fact that Red-footed Booby and Great Frigatebird had been completely extirpated (assuming both species had bred there in the past) and their initial population increase would be expected to be relatively slow, as at least initially it must have been driven solely by immigration, and not by recruitment from an existing breeding population As shrub-nesting species, the Great Frigatebird and Red-footed Booby now pose a dilemma for management. Both species will ultimately be limited by the availability of nest sites on East and Middle islands as few shrubs remain there and most of these have died in the past decade. That nest site availability may already be limiting is demonstrated by recent observations of Red-footed Booby nests positioned atypically just 0.2–0.5 m above the ground on compacted herbaceous material (R. Clarke unpubl. data). The construction of a small number of artificial nesting platforms (*e.g.* Fairchild *et al.* 1985, LeCorre 1997, Rauzon & Drigot 1999) may be required to at least maintain the current populations of these two shrub-nesting species.

It is clear that the designation of the reserve and subsequent enforcement has provided opportunities for seabirds to both re-establish and increase markedly at Ashmore Reef. Such a model for protection may also be worth considering for other 'seabird' islands situated within the MOU 74 Box. In particular, Browse Island situated ~150 km off the Kimberley coast (Fig. 1) would be a clear candidate for increased enforcement. It was once regarded as the most famous of the northern Australian guano islands (Serventy 1952), demonstrating that it was once a significant site for breeding seabirds. However, breeding seabirds were extirpated from the island in historic times as Serventy (1952) reported that "inspection proved a great disappointment as there were no seabirds of any kind, nor any indication that the island had been used as a nesting or roosting place for years". Since that time colonies of Crested Terns have bred there on occasion (*e.g.* Abbott 1979; the authors unpubl. data), but no other seabird species have apparently re-established. That there continues to be a significant presence by Indonesian fishers (*e.g.* 11 *perahus* were anchored in the lee of the island in Nov 2010), and that poaching of turtles continues (R. Clarke pers. obs.), suggests increased enforcement of this reserve may lead to further positive outcomes for breeding seabirds (and turtles) in the region.

Whilst illegal harvesting of seabirds appears now to be largely controlled at Ashmore Reef, other threats to seabirds at this site remain. In particular, the increasing development of the Sahul Shelf for oil and gas extraction (*e.g.* Russell 2005) poses novel threats and challenges for the management of the nature reserve. For example an uncontrolled well release from the Montara H1-ST1 Development Well occurred on 21 August 2009 (Gilbert & King 2010). Situated on the Sahul Shelf 157 km east of the Ashmore Reef National Nature Reserve, the release of gas, condensate and crude oil continued from the well head until the well was successfully intercepted and subsequently plugged on 3 November 2009. By the end of October 2009, evidence of petroleum-based products had been reported at or in the vicinity of Ashmore Reef and small numbers of oiled birds were recovered both at sea and on the islands at Ashmore Reef (*e.g.* Watson *et al.* 2009; Clarke 2010). The extent of the resultant oil slick has been variously reported, with satellite imagery demonstrating that an area of 95,554 km^2 surrounding the Montara Well showed evidence of hydrocarbon contamination at some time during the spill period (Gilbert & King 2010). The impetus for a rigorous ongoing monitoring program targeting breeding seabirds (and shorebirds) at Ashmore Reef that commenced in April 2010 stemmed from this event (Clarke 2010).

A monitoring program for Ashmore Reef seabirds

As a component of the response to the Montara Well release, biannual monitoring surveys to Ashmore Reef (and other seabird islands in the region) have been instigated.

Two surveys per annum is considered to be the minimum number of visits necessary as:

- Seabird species that breed on Ashmore Reef islands do so at different times of year (Fig. 3)
- Some seabird nesting events may be aseasonal. As such the timing of breeding for these species is difficult to predict. Biannual visits increase the probability of detecting these events and adequately documenting them.
- Biannual monitoring provides opportunity to gather more extensive time-series data on year-round resident breeding species such as the Eastern Reef Egret and Brown Booby.

Milton (2005) identified biannual surveys in the periods April to June and October to December as an appropriate strategy to monitor population trends at Ashmore Reef National Nature Reserve. With the benefit

of additional data, including annual counts for the past decade, optimal survey windows have been further refined. The most optimal period is now considered to span the period from early April to mid-May; with a second survey conducted in November. The former coincides with the maximum number of breeding species present, and covers the incubation period of most species. The second visit provides opportunity to assess several seabird populations that would be inadequately covered in April (*e.g.* Wedge-tailed Shearwater), count used nests of some species (Lesser Frigatebird and Black Noddy) to provide a second annual assessment of the breeding population, and provide population-wide counts of all seabirds at a comparable time (October–November) to the bulk of existing data collected since 1996 (Milton 1999, 2005; Bellio *et al.* 2007; this study). A November visit also provides opportunity to count the international significant numbers of shorebirds present at Ashmore Reef (Clarke 2010; Rogers *et al.* 2011), not otherwise discussed here.

Future directions and priorities

Past and present research regarding seabirds at Ashmore Reef has focussed on population sizes and breeding phenology of seabirds within the reserve boundaries (*e.g.* Milton 2005; Bellio *et al.* 2007; this study). Recently seabird research has been further expanded such that annual monitoring will now provide a robust dataset with which to assess inter-annual fluctuations and long-term trends in populations of breeding seabirds at Ashmore Reef. In contrast, a significant knowledge gap exists regarding the at-sea distribution and foraging ranges of seabirds that utilize the reserve as a breeding ground. Such a knowledge gap has management implications given that all species (excluding the breeding herons) are known to forage over marine waters outside of the reserve boundaries on a regular basis (the authors unpubl. data).

With the increasing interest in oil and gas reserves on the Sahul Shelf (Russell 2005), it is imperative that some effort be expended to identify the at-sea distribution of seabirds utilizing Ashmore Reef. In particular areas that provide regular and repeat locations suitable for foraging by seabirds should be identified such that management of marine industries can be better informed.

At present all voyages to and from Ashmore Reef for the purpose of bird surveys employ standard techniques to routinely record at-sea observations of seabirds (the authors unpubl. data). While this provides useful insights into at-sea distribution of seabirds and may potential identify some areas of high productivity visited by breeding seabirds, it is not possible to cover all areas of potential interest on such voyages. A more robust program would involve the deployment of location-reporting technology (geolocators, GPS loggers and satellite tags) on a representative sample of seabird species that utilise the breeding islands. As marine survey data demonstrates even congeneric seabird species (*e.g.* the three breeding *Sulidae*) forage at different distances from shore, it is recommended that such a program extend to cover a representative range of breeding seabirds from Ashmore Reef. Size differences, known dispersive or migratory capabilities, and breeding seasons would all influence the necessary sample sizes and the types of technologies to be deployed. Nevertheless, there exist a range of suitable technologies to undertake such work (*e.g.* Pennycuick *et al.* 1990; Weimerskirch *et al.* 2006; Catry *et al.* 2009; Weimerskirch *et al.* 2009). Such a program would provide managers with a clear understanding of the spatial needs of seabirds that range from Ashmore Reef to feed whilst using the terrestrial environments as a focal point for breeding purposes. It would also help fill the current gap in knowledge regarding the foraging requirements of the seabird community at Ashmore Reef.

Conclusions

This paper concatenates and summarizes existing data concerning seabird populations at Ashmore Reef. Many of these populations are internationally significant and all meet one or more criteria as matters of national environmental significance. Breeding seabirds have clearly benefitted from the protection and increased enforcement that has arisen following the designation of the area as a national nature reserve. Previous monitoring of bird populations at Ashmore Reef, whilst *ad hoc*, has provided valuable insights into the recovery of populations. More recently a seabird monitoring program that seeks to rigorously assess seabird population trends and changes within the reserves has commenced (April 2010). It is recommended that monitoring using the established techniques continue on a biannual basis. It is further recommended that consideration be given to establishing a program to rigorously assess the use of marine resources by Ashmore's seabirds outside of the reserve boundaries.

Acknowledgements: The authors are grateful to Chantal Simakoff-Ellims (DSEWPC) for provision of historic bird data (1979–1992) collected by staff of DSEWPC and its predecessors and for access to GIS data for the Ashmore region. David Milton (CSIRO Marine) responded to requests for information regarding bird records at Ashmore Reef and also graciously provided access to data. Since 2003 surveys in October have been undertaken aboard the MV Flying Fish V. The skipper George Greaves and crew are thanked for their professional conduct and assistance during these voyages. The April 2010 survey was funded by PTTEP Australasia and was undertaken on the MV King Tide.

References

Abbott I 1979 The distribution and abundance of seabirds at sea and on islands near the Mid- and North-Western coasts of Australia. Corella 3: 93–102.

Australian National Parks and Wildlife Service 1989 Ashmore Reef Nature Reserve Plan of Management. Australian National Parks and Wildlife Service, Canberra.

Bellio M G, Bayliss P & Williams A J 2007 A preliminary ecological risk assessment of the impact of tropical fire ants (*Solenopsis geminata*) on colonies of seabirds at Ashmore Reef. Supervising Scientist Report 190, Supervising Scientist, Darwin.

Carter M 2003 Pechora Pipit *Anthus gustavi* in Australia. Australian Field Ornithology 20: 59–65.

Catry T, Ramos J A, LeCorre M & Phillips R A 2009 Movements, at-sea distribution and behaviour of a tropical pelagic seabird: the wedge-tailed shearwater in the western Indian Ocean. Marine Ecology Progress Series 391: 231–242.

Clark P 2000 Ashmore Reef: Archaeological evidence of past visitation. Bulletin of the Australian Institute for Maritime Archaeology 24: 1–8.

Clarke R H 2010 The Status of Seabirds and Shorebirds at Ashmore Reef and Cartier and Browse Islands: Monitoring program for the Montara Well release – Pre-impact Assessment and First Post-impact Field Survey. Prepared on behalf of PTTEP Australasia and the Department of the Environment, Water, Heritage and the Arts, Australia.

Clarke R H, Carter M & Swann G 2009 Asian Brown Flycatchers *Muscicapa dauurica* on Ashmore Reef: First records for Australia', Australian Field Ornithology 26 123–131.

Commonwealth of Australia 2002 Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve (Commonwealth Waters) Management Plans. Environment Australia, Canberra.

Commonwealth of Australia 2009 EPBC Act – Principal Significant Impact Guidelines 1.1. Matters of National Environmental Significance. Environment Protection and Biodiversity Conservation Act 1999. Department for Environment, Water, Heritage and the Arts, Canberra.

Dwyer D 2000 Disaster and recovery: a Rotenese discovery tale for Ashmore Reef (Palau Pasir), North Australia. Bulletin of the Australian Institute for Maritime Archaeology 24: 115–118.

Fairbridge R W 1948 Discoveries in the Timor Sea, North West Australian. Journal and Proceedings of the Royal Australian Historical Society 48: 193–218.

Fairchild L, Mahoney S A & Schreiber R W 1985 Nest material preferences of Great Frigatebirds. Journal of Field Ornithology 56: 236–245.

Fox J 1977 Harvest of the Palm: Ecological Change in Eastern Indonesia. Harvard University Press, Cambridge, Massachusetts.

Gilbert T & King B 2010 Montara Well Release Monitoring Study S7.1 Oil Fate And Effects Assessment: Spill Trajectory Analysis. Final report October 2010. Prepared for PTTEP Australasia. Asia-Pacific Applied Science Associates, Perth.

Higgins P J & Davies S J J F (eds) 1996 Handbook of Australian, New Zealand and Antarctic Birds. Volume 3. Snipe to Pigeons. Oxford University Press, Melbourne.

Johnstone R E & Storr G M 1998 Handbook of Western Australian Birds. Volume 1 Non-passerines (Emu to Dollarbird). Western Australian Museum, Perth.

Langdon R 1966 Our far flung empire 100 miles from Kupang. New Guinea and Australia, the Pacific and South East Asia, June/July 1966: 54–58.

LeCorre M 1997 Diving depths of two tropical *Pelecaniformes*: The Red-tailed Tropicbird and the Red-footed Booby. Condor 99: 1004–1007.

Lunn D J, Best N & Whittaker J 2009 Generic reversible jump MCMC using graphical models, Statistics and Computing 19: 395–408.

Lunn D J, Whittaker J C & Best N 2006 A Bayesian toolkit for genetic association studies. Genetic Epidemiology 30: 231–247.

Marchant S & Higgins P J (eds) (1990a). Handbook of Australian, New Zealand and Antarctic Birds. Volume 1: Part A Ratites to Petrels. Oxford University Press, Melbourne.

Marchant S & Higgins P J (eds) (1990b). Handbook of Australian, New Zealand and Antarctic Birds. Volume 1: Part B Australian Pelican to Ducks. Oxford University Press, Melbourne.

McKean J 1980 Oceanic ornithological survey between Derby, WA and Darwin, NT. Northern Territory Naturalist 2: 8–13.

Milton D A 1999 Survey and Stock Size estimates of the Shallow Reef (0–15 m deep) and Shaol Area (15–50 m deep) Marine Resources and Habitat Mapping within the Timor Sea MOU74 Box. Volume 3: Seabirds and Shorebirds of Ashmore Reef. CSIRO Marine, Canberra.

Milton D A 2005 Birds of Ashmore Reef National Nature Reserve: an assessment of its importanct fo seabirds and waders. The Beagle, Records of the Museums and Art Galleries of the Northern Territory Supplement 1: 133–141.

Pennycuick C J, Schaffner F C, Fuller M R, Obrecht H H & Sternberg L 1990 Foraging flights of the white-tailed tropicbird (*Phaethon lepturus*): radiotracking and doubly-labelled water. Colonial Waterbirds 13: 96–102.

Pike G D & Leach G J 1997 Handbook of the Vascular Plants of Ashmore and Cartier Islands. Parks Australia, Canberra.

Potemra J 2005 Indonesian Throughflow transport variability estimated from satellite altimetry. Oceanography 18: 98–107.

Ramsar Convention Bureau 2009 List of Wetlands of In-ternational Importance. Ramsar Convention Bureau, Gland, Switzerland.

Rauzon M J & Drigot D 1999 Red-footed booby use of artificial nesting platforms. Waterbirds: The International Journal of Waterbird Biology 22: 474–477.

Rogers D I, Hassell C J, Boyle A, Gosbell K, Clarke R H, Minto C & Rogers K G 2011 Shorebirds of the Kimberley Coast – Populations, key sites, trends and threats. Journal of the Royal Society of Western Australia 94: 377–391.

Russell B C 2005 The Ashmore region: history and development. The Beagle: Records of the Museums and Art Galleries of the Northern Territory. Supplement 1: 1–8.

Russell B C, Hanley J R, Kelly R & Guinea M L 1993 Physical features. In Marine Biological and Heritage Resources of Cartier and Hibernia Reefs, Timor Sea. Russell, B C & Hanley J R (eds) Northern Territory Museum of Arts and Science, Darwin.

Serventy D L 1952 The bird islands of the Sahul Shelf. Emu 52: 33–59.

Stokes T & Hinchey M 1990 Which small noddies breed at Ashmore Reef in the eastern Indian Ocean? Emu 90: 269–271.

Swann G 2005a Occasional count no. 7, Ashmore Reef, 21 to 30 January 2002. Stilt 47: 26–33.

Swann G 2005b Occasional count no. 8, Ashmore Reef, 23 January to 4 February 2003. Stilt 47: 34–39.

Swann G 2005c Ornithological Report, Ashmore Reef 23 January to 5 February 2005. Kimberley Birdwatching, Broome.

Thomson J, Kimmerer W, Brown L, Newman K, Mac Nally R, Bennett W, Feyrer F & Fleishman E 2010 Bayesian change-point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications 20: 1431–1448.

Watson J E M, Joseph L N & Watson A W T 2009 A Rapid Assessment of the Impacts of the Montara Oil Leak on Birds, Cetaceans and Marine Reptiles. Prepared on behalf of the Department of the Environment, Water, Heritage and the Arts by the Spatial Ecology Laboratory, University of Queensland, Brisbane.

Weimerskirch H, Le Corre M, Gadenne H, Pinaud, D, Kato A, Ropert-Coudert Y & Bost C 2009 Relationship between reversed sexual dimorphism, breeding investment and foraging ecology in a pelagic seabird, the masked booby. Oecologia 161: 637–649.

Weimerskirch H, Le Corre M, Ropert-Coudert Y, Kato A & Marsac F 2006 Sex-specific foraging behaviour in a seabird with reversed sexual dimorphism: the red-footed booby Oecologia 146: 681–691.

Woodward H P 1917 The phosphatic deposits of Western Australia. Geological Survey of Western Australia Bulletin 74: 9–28.